The Use of Mechanisms in Congestion Pricing*

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Introduction

Transport is the generator of many detrimental effects -- externalities. There are externalities that influence non-transport sectors (noise, accidents, air pollution etc.), and externalities that influence only the participants in the transport system (congestion). Because of these externalities the transport system is not being used at its efficient level, where no more gains can be derived without the negative side-effects being even larger. The reason for this is that individuals do not take into account the detrimental effects they are causing when they make their choice of transport. Hence, there are plenty of room for improvements where at least someone is better off, and nobody else is worse off than in the current situation.

During the past years there has been a hot debate regarding detrimental effects of transport among transport economists, especially as to how these effects should be dealt with and at the same time avoid to many restrictions on economic activity in society. The only consensus to be found in this debate is that any intervention from public authorities should be incentive-based rather than command and control based. Obviously this applies primarily to the economic instruments that a government can use. The incentives should be applied both to induce technological innovation as well as demand based incentives. For economists the target often is to find the most efficient use of resources. Whenever detrimental effects (externalities) are present an individual competitive equilibrium does not use resources efficiently. Using Pigou taxes equal to the marginal external costs ensures efficiency. There are however many problems related to finding the first-best solution[1]. Hence, there are two ways to proceed from this benchmark. One way is to analyse the so-called second-best instruments. This is one of the aims in e.g. *Public Economics* (Sandmo, 1975). The other way is to look for first-best alternatives where some of the (theoretical) problems of the Pigou principle are resolved (or reduced). In this paper this latter approach is followed.

The approach taken in this paper has its origin in *Implementation theory*, which has been developed during the past 30 years. Hurwich (1994) gives an overview of the development, and Corchón (1996) covers the principal theoretical elements. The aim of this theory is to implement socially desirable decisions. This can be translated into a transport setting as the implementation of the most efficient use of the transport system, taking into account all effects (direct, indirect, detrimental etc.). For specific purposes special game forms (called Mechanisms) are designed. A

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[1] In particular the necessary valuation of e.g. externalities is very difficult.

mechanism consists of a set of rules (of the game), a set of players. The mechanisms are designed so that the individually preferred strategies is such that the outcome corresponds to the alternative(s) desired by society (a social planner), here this is interpreted as efficient use of the existing transport infrastructure. However, not many real applications have seen the day of light, most contributions have been of the theoretical kind. In this paper the theoretical contributions are taken a step further. Focus is on a very specific task -- namely the internalisation of transport externalities. To make things as simple as possible, attention is limited to the problem of internalising congestion. There is nothing in the theoretical set-up that prevents a general use of the proposals on all kinds of externalities, the restriction to congestion is only used to make the exposition simpler. In another paper, Kveiborg (2001a) discuss the theoretical set-up of the proposals. In the present paper focus is remained on the more practical parts.

The discussion begin by a theoretical discussion of the problem of externalities and how this can be resolved using economic instruments. This is done in a very simple model with two individuals who both have to commute every day. The commuters each influence the other by delaying the other commuters journey (congestion). It is very easy to generalise this set-up as it is done in Kveiborg (2001a), but for the purpose in this paper there is no need for further complexity, and because the results are equivalent. The model is a simplification in other respects as well. Congestion is the only externality (simplifies the analysis), the agents only demand transport and a common transferable good -- this could be money, which can be used to purchase any other kind of good. An individual's demand for transport cannot be substituted for another individual's transport. Hence, transport is assumed to be spcific to each individual. This implies an assumption that any other economic sector works perfect, that is there are no other externalities present anywhere else in the economy. It is implicitly assumed that transport is a normal good, where more transport are preferred to less. This is a simplifying assumption meaning that it is only necessary to consider transport and not care about other sectors in the economy. However, it is a common assumption in theoretical analysis of transport, and thus not controversial for the results presented here.

Set-up

2 individuals compete on the access to a road. An individual's use of the road does not prevent the other individual's access (hence, the road is not a private good in our normal understanding), but it reduces the other individual's utility of the trip, -- the trip is delayed. E.g. think of transport as speed: higher speed reduce travel time, and the time saved can be used on other activities from which utility can be derived. The presence of another person on the road reduces speed. The two individuals demand transport and money, and the two are substitutable; e.g. an individual is willing to reduce speed or drive less, if he is compensated for the time-loss/loss in utility.

When each individual chooses transport demand or speed he takes into account the transport/speed by the other individual (negative externality), but he does not take into account the effect his own choice may have on the other individual. Aggregately this choice set is sub-optimal. Both could be better of (at least none of them would be worse of) if one of them changes his time of departure or his speed in a direction that decreases the effect his choice has on the other individual.

Solutions:

a) The two individuals can negotiate a solution and find appropriate compensations (Coase, 1960)

b) Introduce a tax on transport/speed. The tax is equal to the marginal time loss (loss in utility) in the optimal transport (Pigou, 1920)
c) Speed limits, limits on amount of transport allowed (Second best solution)
d) Use a mechanism, where each announces how much transport he will demand, and how much he will pay for this to the other, and how much he should be paid to accept the other individuals choice of transport. Differences in announcements of payments are punished by a penalty. This will make both announced payments and compensations equal to the solution in b), and their choice of speed/transport is overall optimal -- no one can increase utility without the other incurring a loss, and total delay is minimised.

In this paper focus is on d). and how this solution can be used in a practical set-up. In particular the use of d) in a road pricing system is considered. The road pricing system considered is a system described in the Danish FORTRIN project (Jensen and Kildebogaard, 1999, and Kildebogaard et al, 2001), which is currently being tested in the Greater Copenhagen area[2]. Other road pricing programmes is also being analysed throughout Europe, many of these are linked together through the PROGRESS programme[3]. Here the differences and similarities between the different projects are not described, but the analysis is confined to the proposed Danish system.

The analysis starts by a formalised description of the simple model outlined above, and continue with the solutions to the problem of externalities in this simple model. Focus is specifically on the new proposal, -- proposal d). The other solution schemes are all very well described in both economic and transport related writings (see. e.g. the books by Verhoef (1996), Verhoef and Button (1998), and Johanssonn and Mattsson (1995)). Varian (1994) propose a Compensation Mechanism aimed at solving the problem with externalities in general in a traditional Arrow-Debreu set-up; Kveiborg (2001a) analyse this mechanism in relation to congestion. The discussion in this paper is based on the papers Varian (1994) and Kveiborg (2001a). However, the model in this paper is a very simplified version of the Compensation Mechanism, but it does clarify the properties, and the potential of the mechanism, – especially as a methodology in relation to a electronic road pricing system.

A simple model with congestion

This section contains a description of a simple example of an economy with three agents each affecting the other agents with an externality. It is demonstrated how the problem of internalising the costs of the externalities into the utility function of the individuals is solved. It is further demonstrated how a specific mechanism (the compensation mechanism) can be used to solve this problem.

Assume that the transport system consists of three agents (e.g. a car driver, a user of public transport, and a user of non-motorised modes) whose travel activities have negative impacts on the utility of the other agents. It is chosen to demonstrate the use of the mechanism in a situation, where the preferences of the agents can be described by utility functions, however the mechanisms work without the reference to utilities, simply based on the (for the planner

[2] A description of the test-project can be found on the homepage: www.akta-kbh.dk.

[3] Homepage: www.progress-project.org.

unknown) preferences of the individuals. The agents can only use their own specific mode[4] for travel x_i, and they demand a common transferable good y_i. The utility functions are assumed known by all other individuals. Utilities have the following form

$$u_1 = A_1 x_1^{\alpha_1} - B_1 x_2 - C_1 x_3 + y_1 \quad \text{(1a)}$$

$$u_2 = -A_2 x_1 + B_2 x_2^{\beta_2} - C_2 x_3 + y_2 \quad \text{(1b)}$$

$$u_3 = -A_3 x_1 - B_3 x_2 + C_3 x_3^{\gamma_3} + y_3 \quad \text{(1c)}$$

where α_1, β_2 and γ_3 belong to the interval (0,1], that is decreasing marginal utility of their own level of transport[5], but constant marginal utility of the externalities generated by the other agents[6]. Furthermore, utility is additively separable in transport (x_i), externalitites ($x_{j \neq i}$), and other goods (y_i).

The agents maximise their utility given the budget constraint $z_i, = q_i x_i + y_i$ where q_i is the cost of transport by the mode specific for agent *i*. In the choice specified by these utility functions the agents disregard the impact the choice of transport has on the utility of the other agents. The solution to the maximisation problems is:

$$x_i = \exp\left(\frac{\ln \frac{q_1}{A_1 \alpha_1}}{\alpha_1 - 1}\right), x_2 = \exp\left(\frac{\ln \frac{q_2}{B_2 \beta_2}}{\beta_2 - 1}\right), x_3 = \exp\left(\frac{\ln \frac{q_{31}}{C_3 \gamma_3}}{\gamma_3 - 1}\right) \quad \text{(2)}$$

Compared to the solution of the social planner's problem, who (we assume) wishes to implement efficient and individual rational outcomes (see note 8), which we describe here by the maximisation of some welfare function based upon utility of the three individuals.

$$\max f(u_1, u_2, u_3) \quad \text{(3a)}$$

$$s.t.\ q_i x_i \le y_i,\ i = 1,2,3 \quad \text{(3b)}$$

$$u_i \ge u_i^0,\ i = 1,2,3 \quad \text{(3c)}$$

Where f is a welfare function[7], u_i^0 is a minimal utility an individual should accept (e.g. the utility level, where no transport is undertaken)[8]. The solution is given by

$$x_i = \exp\left(\frac{\ln \frac{q_1 + A_2 + A_3}{A_1 \alpha_1}}{\alpha_1 - 1}\right), x_2 = \exp\left(\frac{\ln \frac{q_2 + B_1 + B_3}{B_2 \beta_2}}{\beta_2 - 1}\right), x_3 = \exp\left(\frac{\ln \frac{q_3 + C_1 + C_2}{C_3 \gamma_3}}{\gamma_3 - 1}\right) \quad \text{(4)}$$

Traditional welfare theory suggests levying a Pigou Tax (Pigou, 1920) on the individuals inducing them to choose the socially optimal solution. In this case the Pigou Tax corresponds to setting individual taxes of $t_1 = A_2 + A_3$, $t_2 = B_1 + B_3$ and $t_3 = C_1 + C_2$, that is the sum of the marginal external effects caused by an individual (in this case individuals 1, 2, and 3).

[4] We have not introduced the possibility of mode choice. The problem related to different modes competing for road space is included if we choose to interprete part of the external effects as the competition for road space.

[5] We have chosen to model the utility of transport as a positive utility, even though this is actually not true, because utility from transport is derived from the activities reached by the transport.

[6] This is a strongly simplifying assumption, but used to simplify things. For a more general approach see Kveiborg (2001a).

[7] In many applications the utilitarian welfare function $f = u_1 + u_2 + u_3$ is used. However, the methods here work in much more general domains. In the presentation it is ignored that such welfare functions may not exist when few reasonable restrictions are imposed. This is due to Arrow's imposibility theorem (see. e.g. Mas-Colell, Whinston and Green, 1995 for a thorough description of the possibilities of aggregating individual utilities into aggregate utility functions or welfare functions.

[8] This condition is a socalled Individual rationality condition. In most cases this should be equal to the minimal utility an individual can guarantee himself regardless of the choices made by any other individual.

Now, instead of introducing the Pigou taxes the following mechanism is suggested as a means of solving the inefficiency problem.

Stage 1(announcement stage): Every agent *i* announces the compensations t_{ij}^{i}, she should be given in order to compensate her for the loss from delays inferred by agent *j*, and the compensation t_{ji}^{i} she should pay to agent *j* for the delay she inflicts on *j*. (In this example each agent announces four compensations - t_{12}^{1}, t_{13}^{1}, and t_{21}^{1}, t_{31}^{1}).

Stage 2 (Choice stage): Every agent maximise utility by the choice of x_i and y_i, given the announcements made in the first stage subject to a new budget constraint, e.g. for agent 1:

$$\begin{aligned} &\max u_1 = A_1 x_1^{\alpha_1} - B_1 x_2 - C_1 x_3 + y_1 \\ &s.t.\ y_1 = w1 + t_{12}^{2} x_2 + t_{13}^{3} x_3 - (t_{21}^{1} - t_{21}^{2})^2 - (t_{31}^{1} - t_{31}^{3})^2 - (q_1 + t_{21}^{2} + t_{31}^{3}) x_1 \end{aligned} \tag{5}$$

and similarly for the two other agents.

The change in the budget constraint is that the agents receive compensations from the other agents for the inflicted delays (the compensation is set by the other agents), and the agents have to pay a compensation for the delay she inflicts on the other agents. Furthermore they have to pay a penalty if they announce a compensation for the chosen level of transport (and hence, the delay) being different from the level of the compensation announced by the agent suffering from the delay. Hence, instead of having the Minister for Taxation dictating a Pigou tax, the influenced parties decide what the tax should be. Another difference is that a compensation is actually paid to the suffering agents. In a taxing system taxes are centrally collected, and normally (in transport economic models) no account is made of how the taxes collected should be used. Notice, that the compensations received are those announced by the other agents. This means that an individual does not directly decide any of the tax parameters in his own budget constraint apart from the element in the penalty term. It is of no importance how the specific form of the penalty term is (though of course, it should be increasing in the difference).

The problems are solved backwards, where the agents in the second stage take the announced compensations as given. The choices of x_i are then given by

$$x_i = \exp\left(\frac{\ln \frac{q_1 + t_{21}^{2} + t_{31}^{3}}{A_1 \alpha_1}}{\alpha_1 - 1}\right), x_2 = \exp\left(\frac{\ln \frac{q_2 + t_{12}^{1} + t_{32}^{3}}{B_2 \beta_2}}{\beta_2 - 1}\right), x_3 = \exp\left(\frac{\ln \frac{q_3 + t_{13}^{1} + t_{23}^{2}}{C_3 \gamma_3}}{\gamma_3 - 1}\right) \tag{6}$$

It is now easy from (4) and (6) to see, that agents 2 and 3 should announce $t_{21}^{2} = A_2$ and $t_{31}^{3} = A_3$ if the mechanism should implement the first best solution – the Pigou tax solution. In the following it is demonstrated that this is also the case, when the agents maximise utility knowing the outcome in the second stage. To do this, insert the x_i's in the utility function, and solve the resulting maximisation problem with regard to the compensation announcements. That is each individual solves (5) using the equations (6). Doing this implies solving the following first order conditions.

$$\frac{\partial}{\partial t_{21}^{1}} u_1 = 0 \quad t_{21}^{1} = t_{21}^{2}, \frac{\partial}{\partial t_{31}^{1}} u_1 = 0 \quad t_{31}^{1} = t_{31}^{3} \tag{7}$$

$$\frac{\partial}{\partial t_{12}^{1}} u_1 = 0 \quad K_1 \frac{B_1}{(q_2 + t_{12}^{1} + t_{32}^{3})(\beta_2 - 1)} = 0 \quad t_{12}^{1} = t_{12}^{2} = B_1 \tag{8}$$

$$\frac{\partial}{\partial t_{13}^{1}} u_1 = 0 \quad K_2 \frac{B_1}{(q_2 + t_{13}^1 + t_{23}^2)(\gamma_3 - 1)} = 0 \quad t_{13}^1 = t_{13}^3 = C_1 \tag{9}$$

where $K_1 = -\left(\frac{q_2 + t_{12}^1 + t_{32}^3}{B_2\beta_2}\right)^{\frac{1}{\beta_2 - 1}}$ and $K_2 = -\left(\frac{q_3 + t_{13}^1 + t_{23}^2}{C_3\gamma_3}\right)^{\frac{1}{\gamma_3 - 1}}$. The same first order conditions can be found for the two other agents. Hence, the announcements will coincide with the optimal Pigou taxes[9].

To understand why the Compensation Mechanism work, consider the relationship between an announcement and the reaction to this announcement by a specific commuter. This relationship is described in the reaction functions in (6). Rearranging[10] it can be seen that increasing compensation reduce the demanded transport, x_i. This reduce total received compensation for the commuter making the announcement. That this latter will be the outcome is because announced compensations will be equalised, like demonstrated in the derivation of the results. Reductions in received compensations on the other hand reduce utility. Only in the equilibrium derived above will utility gain from reduced congestion be equal to the loss in utility because of reduced compensation. The reaction defined by the equations (6) can be compared with the individual reaction functions to e.g. Pigou taxes.

A second instrument being able to implement a socially desirable level of commuting has now been introduced. The solution is the same as the one implemented using congestion pricing based on the Pigou tax princinple. The main difference is the information needed for implementation under the two systems. In the Pigou tax system, a social planner has to collect information on all commuters individual preferences (regarding speed of travel and congestion, or the individual value of travel time). The gathered information is then used to define the appropriate size of the congestion tax. In the Compensation Mechanism, there is no need for a central planner to collect this information. A second important difference is the use of the taxes. In the Compensation Mechanism distributional effects are taken care of, given the initial distribution of wealth, at the same time as the optimal allocation of traffic is obtained. Under a Pigou tax system, the social planner has to find use of the taxes collected. Optimally the taxes collected should be distributed to the individuals in a non-distorting way, which is happening in the Compensation Mechanism. Hence, in the theoretically defined systems described here, the task under a congestion pricing system does seem more difficult to implement than an incentive scheme based on the Compensation Mechanism. Kveiborg (2001a) discuss these and other problems.

Road Pricing

There are several difficulties in the implementation of a Pigou tax based road pricing system. One of the problems relates to the dynamics in transport – optimal taxes today, may give inefficient traffic levels tomorrow. Day to day changes in the environment for the transport system, – new commuters or other external influences changing the individual value of travel

[9] The other solution where $p_{12}^1 = -q_2 - p_{32}^3$ is not feasible, as this would set the denominator equal to 0 in the following term.

[10] This is easiest to see by the following rearrangment: $\exp\left(\frac{\ln\left(\frac{q_1 + p_{21}^2 + p_{31}^{32}}{A_\alpha}\right)}{\alpha - 1}\right) = \left(\frac{q_1 + p_{21}^2 + p_{31}^3}{A\alpha}\right)^{\frac{1}{\alpha - 1}}$

time. Prior to this point there is an even larger problem of assessing the marginal external costs (or value of travel times in our simple model) in order to define optimal taxes. A large literature is devoted to the valuation of externalities (for a theoretical contribution see Freeman, 1993). It is often argued that it is impossible to implement efficient pricing based on external effects (Trafikministeriet, 2000, and Kildebogaard et al, 2001). The reason given is that it is very difficult to make correct assessments of the external costs. This is exactly the difficulty that the Compensation Mechanism is capable of solving. The Compensation Mechanism only demand that individuals involved make announcements. The mechanism is designed so that optimal behaviour as perceived by the individuals themselves will prevail. Hence, the suggestion made here is to use the Compensation Mechanism as the basis for the definition and updating of the prices. The considerations presented here are preliminary, and further points and objections must be considered in the future if this system should see the day of light. Most of the practical considerations will reduce the probability of implementing the socially desired level of congestion, e.g. because of less flexibility in making announcements (would merely prolong the time before an optimum is found by the individuals).

However, there are several unsolved problems and issues with the practical implementation of the Compensation Mechanism related to a system like the AKTA system[11]. The many difficulties in providing the information needed to assign appropriate taxes has contributed to the use of simpler tax structures – e.g. fuel taxes, parking fees, and registration taxes. These instruments are obviously not perfect instruments to use, and will only incidental lead to optimal use of the infrastructure. In contrast, the proposed Compensation Mechanism may be a good instrument, that can help in defining appropriate taxes. An advantage is that no central planner needs to be involved in the definition of the tax, because he can only approximate the individual preferences, which the individual themselves reasonably can be assumed to know. On the other hand a compensation distribution body is needed for transferring compensations from externality generators to receivers. The model in section 2 clearly demonstrates that optimal taxes (and thus levels of transport) can be obtained without a central planner. What is needed is to design a technical set-up in which the Compensation Mechanism can work – like an appropriate size of the prices (Pigou taxes) in a traditional Road pricing solution also works.

To ensure Pareto optimality (efficient use of the transport system)[12] the proposed system must as a minimum be subject to the following characteristics:

- All interested parties must be allowed to participate – make announcements. This could take care of the individuals not using the road at the specific time still, but derive positive utility from the knowledge that it is possible to use the road at a given speed. Allowing for non-users to participate makes the identification problem difficult. Because, such individuals are not initially identified to the commuters However, in respect to congestion this does not seem like a serious problem, hence, it is no great mistake to exclude non-users from making announcements[13]

[11] A description with some details is given below.

[12] And further individual rational outcomes, which have been ignored in the discussion above. However, the outcomes of the Compensation Mechanism does fulfil this condition.

[13] Things are more complicated if we consider other extra-sectorial externalities like noise, and pollution. E.g. if a noise and pollution free recreational area is of high value even though the same individuals rarely (or never) use this area. Another example is the value I attribute to my parents living in a noise free environment. The noise does not influence my own well-being, but my parents are suffering severely. Many such relevant examples can be found.

- All affected individuals should participate and make announcements. However, sollutions can be introduced into the Compensation Mechanism making non-participating individuals worse of than they would be if they participate.
- Prices (compensations) should be allowed to vary continuously. Consider an additional car, that does not usually use the road at the specific time of the day. The incumbent driver may value congestion different than some of the existing drivers. Hence, if prices were fixed, no adjustment of prices would occur, and optimality would no longer prevail. This seems like a serious objection towards a road pricing system based on the compensation mechanism. However, the objection is even more important under a traditional Pigou based prices. Pigou taxes must also be adjusted continuously in order to sustain optimality, but this implies new assessments of the external effects. Thus, price rigidities are at first glance no more severe under the mechanism based system than under a Pigou based system. On the contrary, the Compensation Mechanism will actually aid in the ease of adjustment towards an equilibrium.
- In accordance with the previous point, drivers must be able to access and leave the road at all times, if prices are to high. This is at first glance a very unrealistic condition to fulfill. However, in the long run this is reasonable, because individuals can choose different residential and working locations in order to change the commuting demands, and thus accommodate their behaviour to prevailing prices.

Besides these theoretical conditions, a more detailed description of how a system should be developed must be described. An attempt is given in the following.

A technological set-up for the Compensation Mechanism

Road pricing is a concept, which have been discussed for a very long period of time as a method for solving the externality problems in transport. Especially congestion pricing has attracted much attention. A Road Pricing scheme can in theory be designed so that prices reflect the marginal external costs – that is Pigou taxation. Until very recently it has not been possible to implement such a system, because of technical difficulties. Attempts have been made in Hong Kong, whereas the toll-ring systems implemented in Norway are only approximations of a road pricing system based on actual driving patterns. In the last couple of years developments of technical solutions have been undertaken.

The AKTA project is a real test of an electronic based road pricing system. Approximately 500 individual cars are used to test the equipment, and simultaneously to test two alternative tax scenarios. The technology is based on GPS receivers and GIS to connect the geographical location with an underlying road infrastructure. In each of the 500 cars a small computer with the relevant software has been installed. The system identifies the exact location of the car every second. This location is linked to a specific road (in the GIS system). Every road has attached a specific price per km. Thus the price can be calculated by multiplying the distance on each road times the price on this specific road. In the project two different price scenarios are being tested. One is a zonal based scenario, where Greater Copenhagen is divided into a number of differently zones, and the number of zones determines the price. The second scenario is a real kilometer based scenario, where prices differ on different types of roads. Different price levels and variations are being tested, but common for all is that the number of different prices is restricted to maximal 5 different prices and a supplementary fee in peak hours. To make things as realistic as possible each of the drivers is endowed with an account with a specific amount of money. By choosing optimal driving behaviour (even changing modes etc.) the drivers can save money, which they can keep after the project termination. The reason for this is to make the test as close as possible to a real situation, where individuals are using their own money.

In the FORTRIN project different methodologies for updating prices have been thought of. One of the available technologies is the RDS system used for making traffic-announcements. This system can be used to transmit information of updated prices etc. to the system in the car. Other possibilities are short distance transmitters at gas stations. However, for a very dynamic price structure as the one considered in relation to optimal pricing, and the Compensation Mechanism in particular, the system based on RDS seems like the most appropriate. This part of the system has not yet been developed.

The technology in the FORTRIN/AKTA project thus looks like a system very suitable for implementing efficient congestion pricing. However, the price scenarios suggested above does not fulfill the necessary conditions for efficiency. Furthermore the prices used in the tests are only approximately based upon assessments of travel time values (or in general values of other detrimental effects). It is not the intention of the project to design a system for internalising external costs of transport, however, it could be one of the solutions. On the other hand it has been the increasing congestion in the Greater Copenhagen area that is the reason for undertaking the project

Having defined the technological set-up in which the proposed mechanism could work, several other problems have to be solved. First, the question on how individuals should make their announcements.

There are several possibilities of how individuals can make their announcements. Among these are phone, cellular phones, and internet. Each individual is identified by a personal code to identify who is making which announcements. In Denmark the civil registration number can be used, otherwise personal identification must be developed. For practical purposes every individual should be able to adjust his or her announcement once every day for each of the trips he is considering. When congestion is the only externality under consideration, it is only necessary for an individual to consider the specific commuter trips he is planning. Further, because of the assumption that all vehicles contribute equally to congestion, there is no need for the individual commuter to announce more than one compensation, which he think he should be paid for the delay caused by the other commuters. He must make separate announcements related to each of the other commuters, for the delay he himself is causing. This latter set of announcements can, however, still be an enourmous task to accomplish. This is a problem yet to be tackled, but Kveiborg (2001b) is proposing some ideas as to how this can be done.

A second problem related to the issue of announcements is that commuters should only be allowed to commute on the specific route and time-period for which they have made announcements. This is to ensure that prices exists for the specific choice of an individual commuter. If no announcement has been made, what penalty should then be used in the penalty term in (5). Below this point is considered a bit further if either announcements of zero, or the average announcement is used. Different solutions to deter illegal commuting can be thought of. One solution is to use technical restrictions preventing the car from moving if an announcement has not been made. This is a solution being considered in the FORTRIN project to ensure that drivers have money on their payment card (a smart card very much alike prepaid phone cards) and thus do pay for their commuting or use of the road infrastructure. The restriction is not strong. There is no restriction on the number of announcements an individual may submit regarding routes and time-periods. A commuter only has to pay in the case he is actually commuting (e.g. one specific route and time-period). Hence, any individual can submit announcements for all the routes and time-periods he is considering, and in the end choose the route and time-period that suits his demands, and optimises his individual utility maximisation programme. However, this is related to the frequency of announcements. To give individuals an actual possibility of considering the different alternatives, compensations must e.g. be the ones announced a day before.

Repeating the announcements in an arbitrarily number of times, the individual will gradually learn what route and period that is an optimum, and hence, only consider and update this specific announcement[14]. The procedure sketched here is similar to the procedure an individual commuter must undertake, when he is assessing the alternatives and choose specific announcements, routes and time-periods. In brief, nothing here prevents the implementation of the mechanism.

In reality there will most likely be a number of non-announcers where some commuters either do not want to or forget to submit their announcements. Two immediate ways of solving this problem can be thought of. First of all, no commuter can escape paying compensations (unless all other commuters announce a zero compensation). The question then is, what amount should be paid? It could either be assumed that no-announcement is equal to a zero announcement, or it could be equal to the average of all other announcements for the specific alternative. There is no need to consider missing announcements for compensations to be received, because this implicitly means that the individuals do not feel influenced by congestion, and hence do not claim for any compensation. If it is assumed that non-announcements are equal to zero the penalty term will be quite large, compared to a situation where an announcement has been made[15]. Hence, there will be an incitement to make sure that individuals make an announcement for the alternative considered. Using an average means a minimisation of the penalties. The individual can in both he average compensation, and in the zero compensation improve on the solution by changing any announcement to the optimal level. Under the second (average) solution the incentive to make announcements is smaller than under the first solution. On the other hand the average could possibly help the individual in finding the right level of his announcements, and hence improve the speed of adjustment towards the socially optimal announcements and level of congestion.

Another extreme can also be thought of. When individuals realise that they decide (part of) the compensations paid by the other drivers, and that they can induce any level of congestion by their announcements, what then prevents the announcement of an arbitrarily high compensation? Nothing is the first answer. But recalling the comments on why and how the mechanism works. There is a trade-off between congestion and compensations received. More congestion means more compensation. Both no congestion and compensations induce utility, hence at some point no gain can be obtained by rising compensations. It is thus the individual demand for money that prevents the individuals from making extreme announcements.

This obviously works in theory, but in reality there will exist individuals with such extreme valuations of no congestion (e.g. ATTAC[16]). In the system described here nothing restrict such individuals from making announcements. If nothing is added to the system it will obviously

[14] However, he must continuously consider all alternatives to evaluate whether any of these would give higher utility. Changes could happpen due to changed announcements, additional (or fewer) commuters using both his curent alternative and the other alternatives.

[15] Given that all announcements is positive, which is implicitly assumed when congestion is a negative externality for the individuals.

[16] In the case of congestion ATTC does possibly not have an opinion on that, but the statement would possibly be true if other externalities are taken into consideration – e.g. pollution and noise.

break down because of the extreme compensations that must be paid. Some restriction on the possible announcements must be made. One possibility is to restrict which announcements are included in the calculated compensation. If only compensations made by individuals actually using the road (and thus suffering from the congestion induced) are included, no single individual can cause the entire system to break down. However, a large group of individuals could collectively cause great problems on the system.

Another possibility is to infer some kind of No-veto-power restrictions. Such a restriction says that no single individual can enforce his preferred alternative (here no travel) if every other individual prefers at least some congestion. However, this restriction is rather difficult to implement in reality. One pragmatic way is to set an upper limit on the possible announcements. In this paper the consequences of extreme announcements will not be analysed further.

It was argued above that prices should optimally be subject to changes all the time. However, this will obviously not meet one of the user conditions that Jensen and Kildebogaard (1999) have identified as being necessary for the implementation of a road pricing system. The condition is that individuals should be able to calculate the price of a specific trip before undertaking it. When the optimum has been obtained, this is obviously not a relevant objection, because both prices and choices of commuting has been determined, and no further uncertainty exists. However, if we allow for adjustments in a more continuous manor, there will be some uncertainty and continuing adjustment of the prices. Hence, it is impossible to foresee the price of a specific trip. It is necessary to accept something less than optimal in this case[17].

The situation can be compared to purchasing a liter of milk. Even though the price of a liter of milk tend to be fixed, there are some day to day variations, and variations from one shop to the next. It is only in the situation where the price of milk is learned that the ultimate decision whether to buy or not is taken. Potentially this is similar to the situation drivers are facing. Hence, the decision of whether to use one route or the other, to depart at one time or the other is no more difficult than purchasing a liter of milk. Add to the decision of milk the complexity that many other items must be purchased. The decision of which shop to use depends on many partly unknown prices. Making the optimal decision (e.g. choosing the shop where prices are the lowest and quality is the best) is very difficult. But as time goes, we gradually learn which shop that fulfills demand, thus this shop will be chosen more often than are competing shops. Hence, in principle the difficulty related to optimal choice of commuting dependant on price is similar to the choices faced every day on other markets, but relatively more complex though.

The discussion above does suggest that a daily update of prices would be acceptable Adjustments more often than that would possibly be to difficult for the drivers to accommodate behaviour to. This is also due to the discreteness of the problem. When a trip is started it is very difficult to substitute it with another transport solution (e.g. another mode), and thus to change behaviour because the price had suddenly changed. Even the option of using different routes is only partly a reason for allowing prices to change continuously, because drivers are constrained in their possibilities of analysing alternatives when driving.

What are the consequences for optimality in this constrained price adjustment set-up? It is obvious that such a system is not suited for sudden changes in mobility, where e.g. a large number of new drivers enter the system at one time (or depart which is similar), or when a traffic accident block a road. On the other hand drivers do not have the option of leaving the system

[17] Unless the price is checked imediately before the trip and that a price of a specific trip is fixed when the trip is undertaken. However, this will possibly result in further problems such as changing route after a price of another more expensive route has been given. To deal with this further adjustments must be made.

when such a change in mobility (followed by a similar change in prices) occurs. Hence, that prices do not adjust to such incidences is perhaps not a prohibitive problem, it is actually very much alike the situation in the housing market.. In summary, a non-continuously price adjustment could be appropriate. When considering the point just made, it should be remembered that the same kind of inefficiency will prevail in a price system based on Pigou pricing if such prices are not updated continuously.

It is not difficult to see that the proposed mechanism when expanded to N commuters and a complete infrastructure becomes extremely large. This will definitely make the task of announcements burdensome for the individuals. In the optimal case (the case described above) each individual should consider all other individuals and, make announcements accruing to each of them, both for their choice of commuting and for his own choice. However, this is obviously not possible. Even the task of identifying whom the relevant individuals are is quite difficult, and when possible only at very high (transaction) costs. This difficulty does look prohibitive for the practical system. However, related to congestion many simplifying assumptions can be made. First of all, it is not unreasonable to assume that all cars contribute equally much to congestion[18]. This means that an individual can simply be asked to announce only one value of compensation for the delay he is suffering, and one value of the compensation he will pay for his choice of commuting regardless of whom he is interfering with. This procedure greatly simplifies the individual's task of making announcements. However, the Compensation Mechanism must be adjusted in order for efficiency to prevail in this new setting, if indeed efficiency can be obtained after the adjustment. For a further discussion of this point see Kveiborg (2001b).

One issue, which remains to be discussed is individual understanding of congestion prices based on the Compensation Mechanism. In the theoretical analysis it is assumed that all individuals posses perfect and complete information. This means that each individual knows the consequences of his or her announcements and choices. Hence, optimal behaviour can be solved for by each individual. If individuals do not posses perfect information about their counterparts, they cannot make optimal announcements. However, in the long run adjustment of prices to an equilibrium is (in theory) likely to happen. It can in fact be shown that this will happen if drivers when making announcements use a so-called best-replay strategy, where adjustment in announcements are made only based upon announcements (and choices of driving) in the previous period (here the day before). This is demonstrated in Kveiborg (2001b).

Related to the individual understanding of the mechanism is the question of complexity. In a number of studies of public attitudes on road pricing (e.g. Jones (1996), Schlag and Teubel (1997) and Kildebogaard et al, 2001) it is often found that complexity is perceived very negatively. Price structures should be as simple as possible. This attitude is obviously related to the ease with which individuals may be able to find optimal behaviour (given the price structure). Whether it is also directly related to the possible comprehension of a complex price system is not unambiguous. This means, however, that further consideration on how complex the price structure can be must be made before an actual imlementation.

Conclusion and further relevant issues

In this paper a new methodology for implementing social optimal congestion levels in an urban region have been discussed. The new method is capable of implementing the same outcomes as a traditional Pigou based congestion pricing scheme. The method proposed is advantageous in the

[18] Even though different driving behaviour influence congestion differently, this is of minor importance here.

information level needed for a social planner in the achievement of the optimal solutions. However, this is at a cost to the individual commuters who in order to decide on the levels of compensations that must be paid in the transport system, must posses more information. In other words, the information necessary for efficient use of the infrastructure has been moved from a central planning authority to the individuals themselves. This must obviously be an improvement, because individuals should be expected to possess better knowledge of their own preferences than can be guessed by an outsider. But at the same time it is demanded that the individuals must posses perfect information of all other individuals in the system. Hence, potentially this is a situation even worse than having one central planner collecting the information. However, Kveiborg (2001b) demonstrates that the solution is stable, meaning that eventually individuals will learn what the optimal announcements are.

The proposed mechanism is designed so that choices of non-optimal levels of congestion prices give lower economic welfare (using the terminology from traditional welfare economics). The efficient solution is in the Compensation Mechanism a self-selecting outcome, meaning that it is chosen by the individuals if they are given a free choice, subject to the imposed game form.

Many practical things must be considered and analysed before a road pricing system based on the Compensation Mechanism can be implemented. In this paper a few considerations are given. Most of the considerations are relatively theoretical of its kind, but some are also of practical character. Based on the discussions it is difficult to conclude unambiguously that the Compensation Mechanism is well suited in road pricing. Here it has been argued that some of the difficulties can be overcome by the use of a system based on GIS and GPS like in the FORTRIN project. However, finding a technological setting does not necessarily imply that the problems that individuals face when they are asked to make announcements are solved. A few potential simplifications has been proposed. The most important of these is the realisation that every car contribute similarly to congestion, and that individuals are indifferent to which car is actually causing congestion, and whom they themself affect with their driving. Hence, when only congestion is considered things can possibly be made relatively simple. Unfortunately the simplifications just suggested does not hold when other externalities are taken into account. Noise an emissions are highly dependent on the individual car. Thus, announcements must be made specific to each type of car. There is also the question regading the individual valuations of lost travle time that plays a significant role in this respect.

Practical use of mechanisms have been very few. Lindeneg and Navrud (1998) is one such attempt, where liming of a Swedish lake is the subject. Hence, it is very difficult to say anything about how individuals understand and behave when they are participants in a mechanism. One way to find out is to design more case studies. One approximation could be made in connection with the AKTA project. This is a manageable size involving only up to 500 individuals. Instead of using predefined price scenarios like those described in the previous section, the individuals should be asked to make announcements, and prices be determined on this basis. To desgin such a case study further considerations must obviously be made. Especially important is the problem that more drivers than the 500 in the AKTA project use the infra structure, and hence that announcements and prices only accrue to these specific 500 cars, and potentially no reduction in congestion will occur. The discussion of implementation of mechanisms in real cases has not been part of this paper. It is left for the future to design such case studies.

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